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THE ARL/FED ANECHOIC CHAMBER

R. C. Marboe and J. M. Fitzgerald

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This report documents the design and acoustic characteristics of the Applied Research Laboratory Department anechoic chamber. It is located on the above-console deck of the Garfield Thomas Water Tunnel situated so as to allow its use in conjunction with the Axial Flow Research Fan (AFRF). The internal free dimensions of the chamber are 2.74 x 3.05 x 1.98 meters (9 x 10 x 6.5 ft.). The sound absorbing walls are composed of polyurethane foam acoustic wedges, air voids, embossed

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) acoustic foam wall lining, plywood and wood frame members. Air intake ducts, baffled and lined with a lead-foam sheet, provide an adequate air volume for the AFRF. Based on measurements of transmission loss and inverse square law, the chamber is considered anechoic for frequencies above 230 Hz and semi-anechoic for lower frequencies.

Subject: The ARL/FED Anechoic Chamber

References: See page 9

Abstract: This report documents the design and acoustic characteristics of the Applied Research Laboratory Department anechoic chamber. It is located on the above-console deck of the Garfield Thomas Water Tunnel situated so as to allow its use in conjunction with the Axial Flow Research Fan (AFRF). The internal free dimensions of the chamber are 2.74 x 3.05 x 1.98 meters (9 x 10 x 6.5 ft.). The sound absorbing walls are composed of polyurethane foam acoustic wedges, air voids, embossed acoustic foam wall lining, plywood and wood frame members. Air intake ducts, baffled and lined with a lead-foam sheet, provide an adequate air volume for the AFRF. Based on measurements of transmission loss and inverse square law, the chamber is considered anechoic for frequencies above 230 Hz and semi-anechoic for lower frequencies.

Acknowledgment: This work has been supported by the Naval Sea Systems Command Codes 05H and 63R31.

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I. INTRODUCTION

The need for an anechoic chamber with a cut-off frequency low enough to allow rotor noise studies resulted in the redesign of the former ARL/FED semi-anechoic chamber [1].* The chamber described in this report was subsequently constructed and acoustically calibrated. The chamber is located on the above-console deck of the Garfield Thomas Water Tunnel in a position where it may be used with or without the Axial Flow Research Fan (AFRF). Figure 1 shows this location on the deck. The free internal dimensions are 2.74 m (9 ft.) wide x 3.05 m (10 ft.) long x 1.98 m (6.5 ft.) high. Acoustically treated air ducts supply an adequate volume of air for the AFRF. The chamber could be employed for rotor studies, inlet configuration studies, microphone/speaker calibration or other acoustic programs requiring at least a semi-anechoic chamber.

II. DESIGN

The chamber was designed for an overall cut-off frequency of 250 Hz. The polyurethane foam acoustic wedges were commercially prepared using dimension specifications obtained from Beranek and Sleeper [2]. The dimensions chosen correspond to a wedge anechoic cut-off frequency of 170 Hz. This is under the required 250 Hz frequency and provides a larger sound absorption area. Though some wedges required some modification, their dimensions still satisfy the 250 Hz dimensions.

The major design requirement which sets this chamber apart from the previous one is the necessity of ducting air into the chamber for the AFRF. Baffled and lined compact ducts were designed to attenuate 25 dB yet result in as low a flow resistance as possible.

III. CHAMBER SPECIFICATIONS

A. Geometry

The existing wooden wall, ceiling, base and floor frames from the previous semi-anechoic chamber were reused. They are specified by Lauchle and Wong [1].

The chamber rests atop a support platform built to raise the chamber to the centerline of the AFRF. This platform is filled with a plastic encased 20 cm layer of fiberglass recovered from the previous chamber. The wooden framework base, measuring 3.96 m (13 ft.) wide x 4.27 m (14 ft.) long, is bolted to 12 commercial kinetic isolators which sit atop the support platform. The spaces in the floor directly above the base are covered with a 25 mm (1") lead-foam liner beneath a turkey wire floor cover. This provides necessary sound and vibration attenuation from beneath the chamber. Figures 2 and 3 give views of the entire chamber.

The wall and ceiling construction consists of plywood, acoustic foam liner and commercially prepared foam wedges. This is shown in Figure 4. The floor of the chamber has wedges mounted on removable

* Numbers in brackets denote references at the end of the report.

19 mm (3/4 in.) plywood sheets which rest on the turkey wire covered floor. These can be lifted and removed from the chamber to work on test equipment. Several single wedges lift off for single stepping points.

For directivity measurements, a permanent microphone boom is installed. A stepping motor allows 1.8° angular increments for surveys. The maximum boom radius for a full 180° survey is 1.37 m (4.5 ft.) from the center of the inlet.

It should be noted that the height of the chamber exceeds the height of the overhead crane rail; therefore, new crane stops were installed previous to the chamber. This reduces the range of the crane by about 4.5 m (15 ft.) A 1.7 m (5.5 ft.) x 2.1 m (7 ft.) walk platform was also built at the level of the door. The door may be rolled into and out of the door frame and rested on the walk platform when not in use.

B. Air Inlets

Operation of the AFRF in conjunction with the anechoic chamber necessitated construction of air passages into the chamber. This was accomplished by raising the walls 51 mm (2 in.) off the base and the ceiling another 51 mm (2 in.) off the wall. A duct arrangement was added around the top and on three sides of the bottom with a plywood cover on the bottom of the fan inlet wall. These ducts were baffled and lined with a foam-lead-foam sound barrier. A typical cross section of the intake duct is shown in Figure 5.

C. Use With and Without Fan Ducts

Mounting of test ducts is done through the fan inlet hole. The AFRF fits through the hole and the bellmouth can be mounted on it from the inside of the chamber. Other types of ducts can be mounted in the fan inlet hole if their diameter is less than 63 cm (25 in.) In this case, the AFRF needs to have a section removed and the entire unit rolled back. For each duct configuration or when the fan inlet is covered, wedges can be mounted to fill the wall. Each wedge around the fan inlet is individually mounted with velcro.

IV. CALIBRATION

A. Ambient Noise

Ambient (or background) noise levels were measured in the anechoic chamber without the operation of the water tunnel test facilities or ancillary equipment. Therefore this represents the most quiet background condition that may be achieved.

Figure 6 illustrates the narrow band spectral results obtained. Overall, the ambient noise levels are very low although significant low frequency sound (i.e. below 20 Hz) exists within the chamber. Additional peaks are apparent at the line frequency

(60 Hz) and its first harmonic (120 Hz). The peaks observed at 395 Hz and 800 Hz are most likely harmonically related although their origin is unknown.

It is recommended that high pass filtering be used for the measurement of low level sound sources within the chamber. This will prevent signal overload caused by the low frequency sound in the chamber. Improved cable shielding and placement will help to reduce line frequency noise.

B. Inverse Square Law

In an ideal free-field, the near-field sound intensity decreases with the fourth power of separation distance between source and receiver. As this separation is further increased, the decrease in sound intensity obeys an inverse-square law which signifies the far-field condition. Skudrzyk [3] describes this result in detail for a simple source.

To verify the free-field properties of the anechoic chamber, measurements of the inverse-square law were performed. Figure 7 illustrates the test set-up employed. All measurements were performed along a horizontal diagonal of the chamber, 2.0 m (6.6 ft.) above the floor. One set of measurements was conducted with the loudspeaker source one foot off-center and another set with the source five feet off center. The microphone was traversed in one-foot increments along the diagonal on the speaker axis. The loudspeaker was driven with pure tones at constant voltage from 100 Hz to 15 kHz. The microphone was calibrated with a B & K type 4220 Pistonphone and calibration was checked at the conclusion of the measurements (no discrepancies were found).

Results

The results of the inverse square law measurements are summarized in Figure 8. A 6 dB drop in sound pressure level per distance doubled of separation of the source and microphone indicates a good free-field condition. Figure 8 indicates such a condition for frequencies above 200 Hz. Scatter at lower frequencies indicate a semi-anechoic condition due to the presence of standing waves. Placement of the source near a corner does not substantially alter the free-field simulation above 200 Hz. It should be noted in Figure 8 that when the microphone is within 30 cm (1 ft.) of the wall, a wall interaction effect is shown. This limits the volume of the free-field to within a quarter wavelength of the chamber walls. Also, directivity measurements are limited to 1.37 m (4.5 ft.) from source for $\pm$ 90° from axis and 1.95 m (6.4 ft.) from source for $\pm$ 45° from axis.

C. Transmission Loss

The transmission loss is a measure of the amount of noise attenuation provided by a sound insulating barrier. This attenuation, as a function of frequency, was measured at four positions using the test set-up illustrated in Figure 9. The measurement positions were:

1 Side Wall - .91 m (3 ft.) from an end, through the wall

2. Side Wall - .91 m (3 ft.) from an end, through the door

3. End Wall - .91 m (3 ft.) from an end, through the fan inlet wall with the fan duct closed

4. Side Wall - .91 m (3 ft.) from an end with the source and external microphone vertically positioned at the duct inlet, through the duct

The loudspeaker was driven by pure tones, at constant voltage, ranging from 40 Hz to 1 kHz. Both microphones were calibrated using a B & K type 4220 Pistonphone and their levels were equalized using the input attenuators on the Spectral Dynamics 360 analyzer. Use of the two channel feature of the SD 360 permitted direct measurement of the transmission loss.

Results

The transmission loss as a function of frequency is shown in Figures 10 through 13. Figures 10 and 11 show the attenuation for a typical wall with 12.7 mm (1/2 in.) plywood. Figure 12 gives the transmission loss for the fan inlet wall,19.1 mm (3/4 in.)plywood, with the fan inlet hole closed. The attenuation of noise by the air intake duct is above 30 dB for frequencies above 120 Hz as seen in Figure 13. This compares favorably to the design expectation of 25 dB.

For each of the walls, note that the transmission loss exceeds 30 dB for frequencies above 230 Hz.

Directivity

To verify the symmetry of the free-field within the chamber directivity measurements were performed. The test set-up employed is illustrated in Figure 14. The loudspeaker was positioned at the end of a 20 cm (8 in.) diameter fan duct in the center of the fan inlet. The loudspeaker was driven with pure tones at constant voltage ranging from 100 Hz to 1kHz. The microphone was positioned one meter (3.3 ft.) from the center of the loudspeaker on a swinging boom. The boom's position was controlled by the stepping motor shown. The microphone was calibrated with a B & K type 4220 Pistonphone. Measurements were performed at 15-degree increments within the forward 180 degree arc of the loudspeaker.

The results obtained are illustrated in Figures 15 and 16. The range of tones is representative of the range of fundamental blade passage frequencies of possible test rotors. Aside from anomalies due to source directivity and wall interaction effects, the sound field is very uniform at all frequencies including those for which the chamber is only weakly anechoic (i.e. below 150 Hz).

V. CONCLUSIONS

1. Based on the acoustic calibration, the ARL/FED anechoic chamber is moderately anechoic for frequencies above 230 Hz and semi-anechoic for lower frequencies.

2. Inverse square law tests indicate spherical spreading for frequencies down to 200 Hz, indicative of a free field condition. For frequencies down to 100 Hz, the spreading is moderately spherical.

3. The transmission loss provided by the chamber exceeds 30 dB for all frequencies of interest.

4. The chamber may be used with or without the Axial Flow Research Fan and can be configured for other ducts up to a 65 cm (25 in.) diameter.

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3. Skudrzyk, Eugene, The Foundations of Acoustics: Basic Mathematics and Basic Acoustics, Springer - Verlag, New York - Wien, 1971, p. 344-375.

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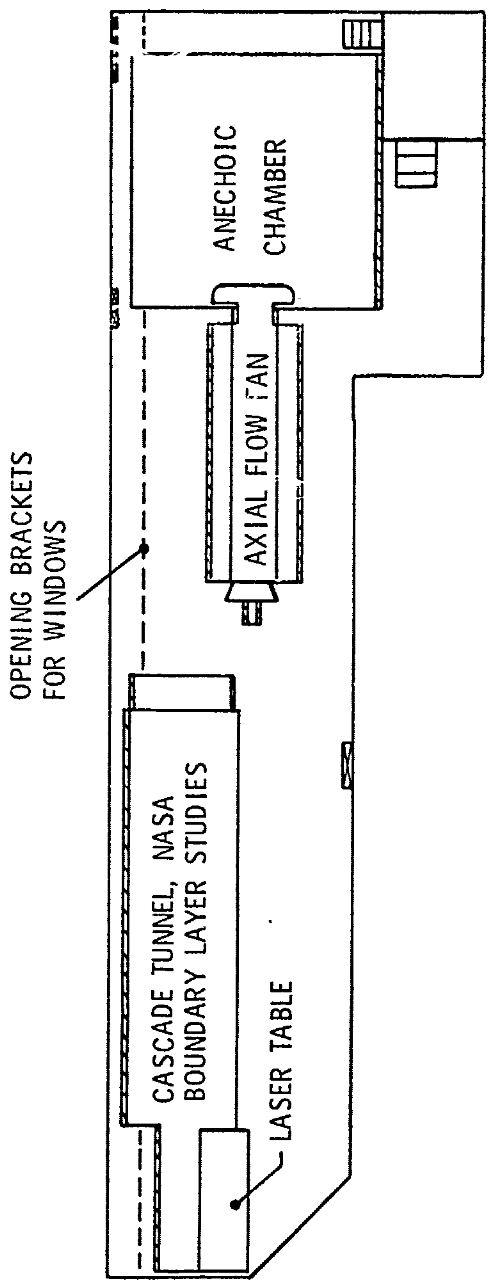

Figure 1 Location of Anechoic Chamber on Above-Console Deck

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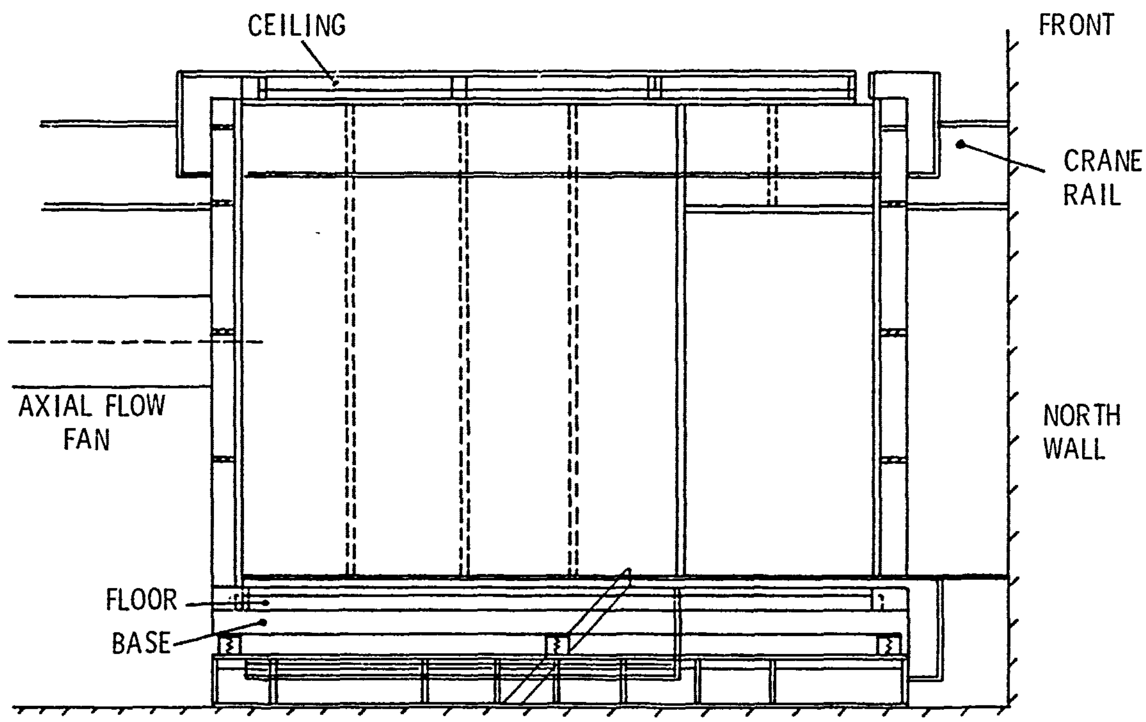


Figure 2 Front View of Anechoic Chamber

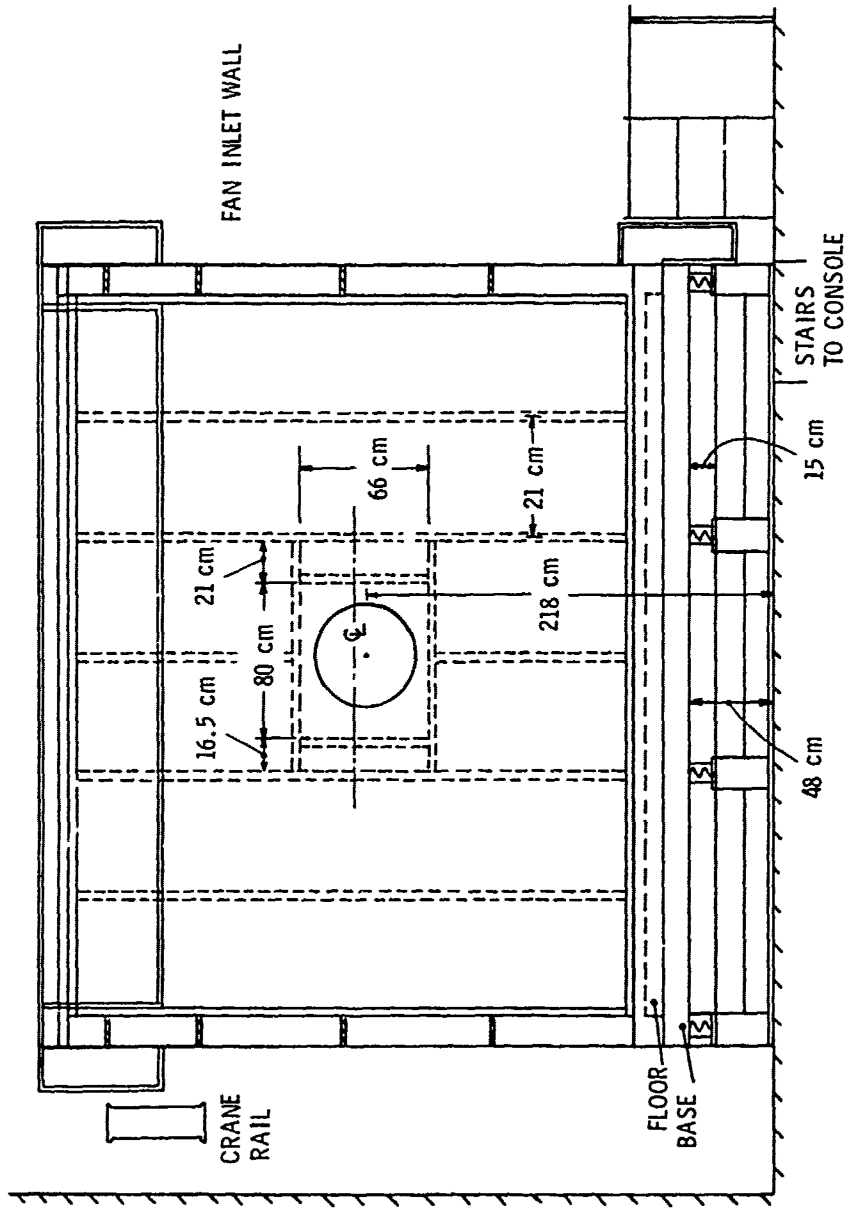


Figure 3 Fan Inlet Wall

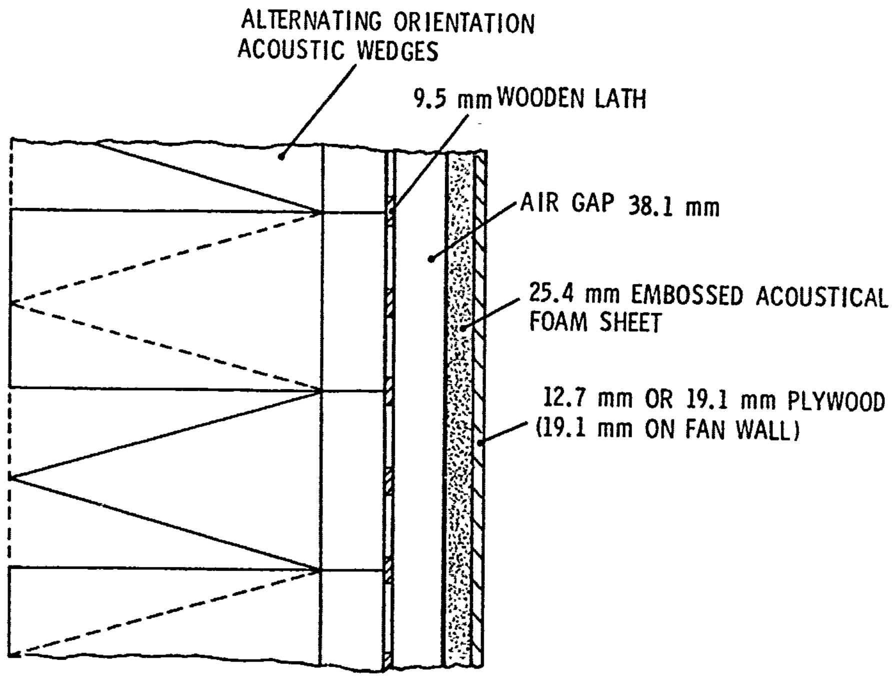


Figure 4 Cross Section of Chamber Wall

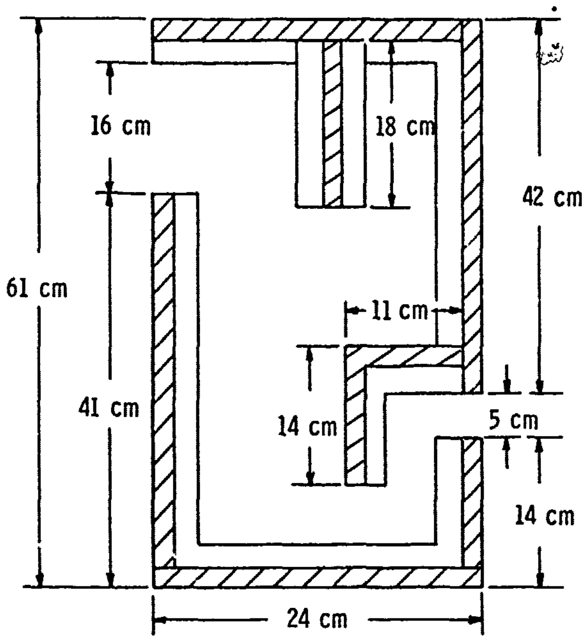


Figure 5 Typical Cross Section of Air Intake Duct

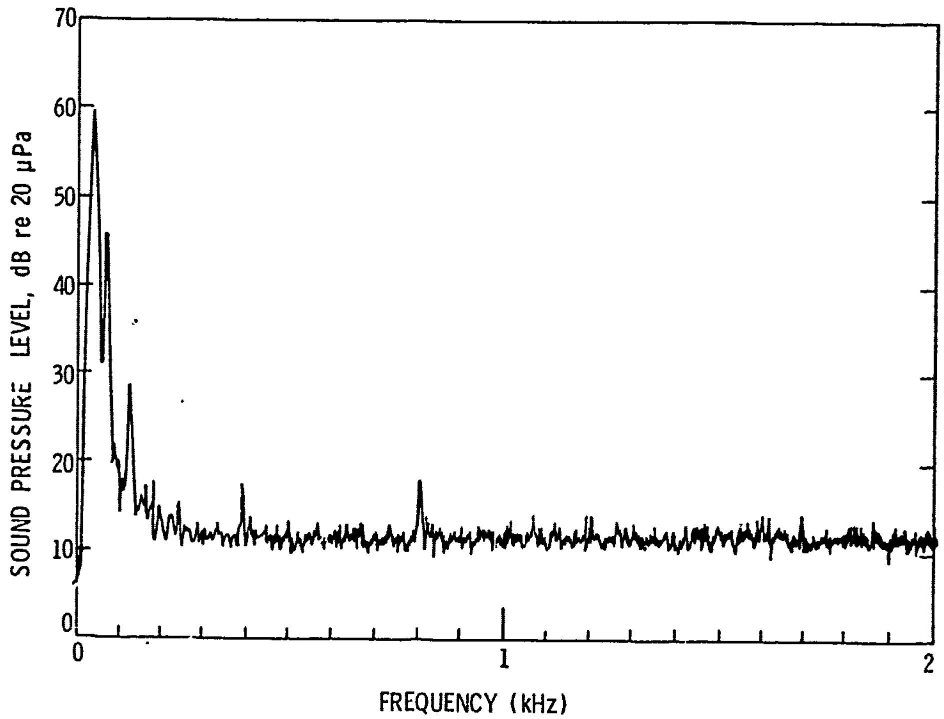
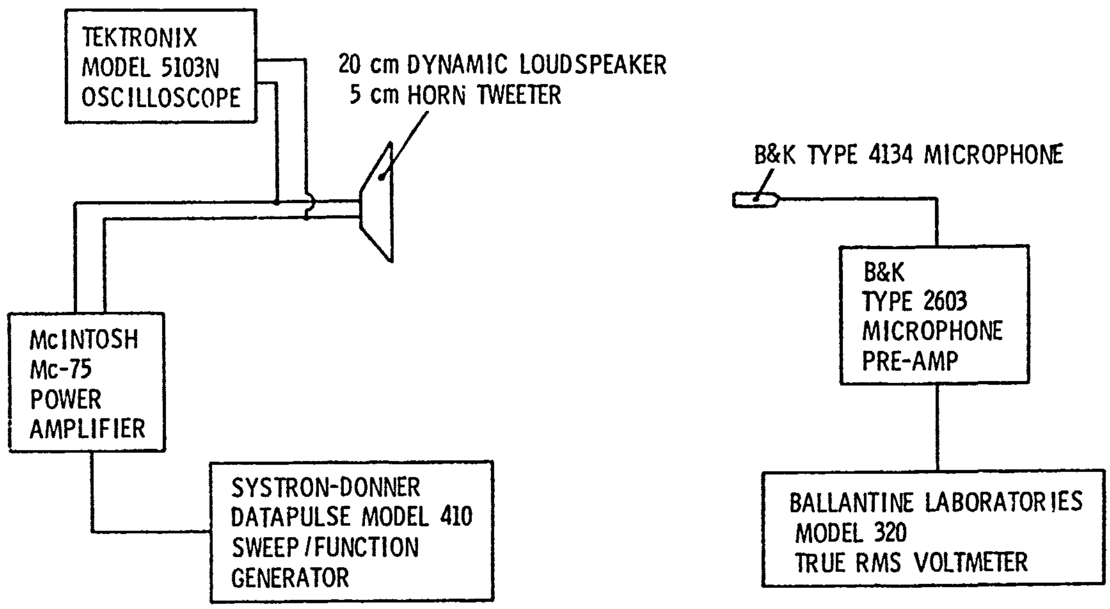


Figure 6 Ambient Noise Sound Pressure Spectrum



NOTE: MICROPHONE CALIBRATION CONDUCTED WITH B&K TYPE 4220 PISTONPHONE

Figure 7 Instrumentation Schematic For Inverse Square Law Measurement

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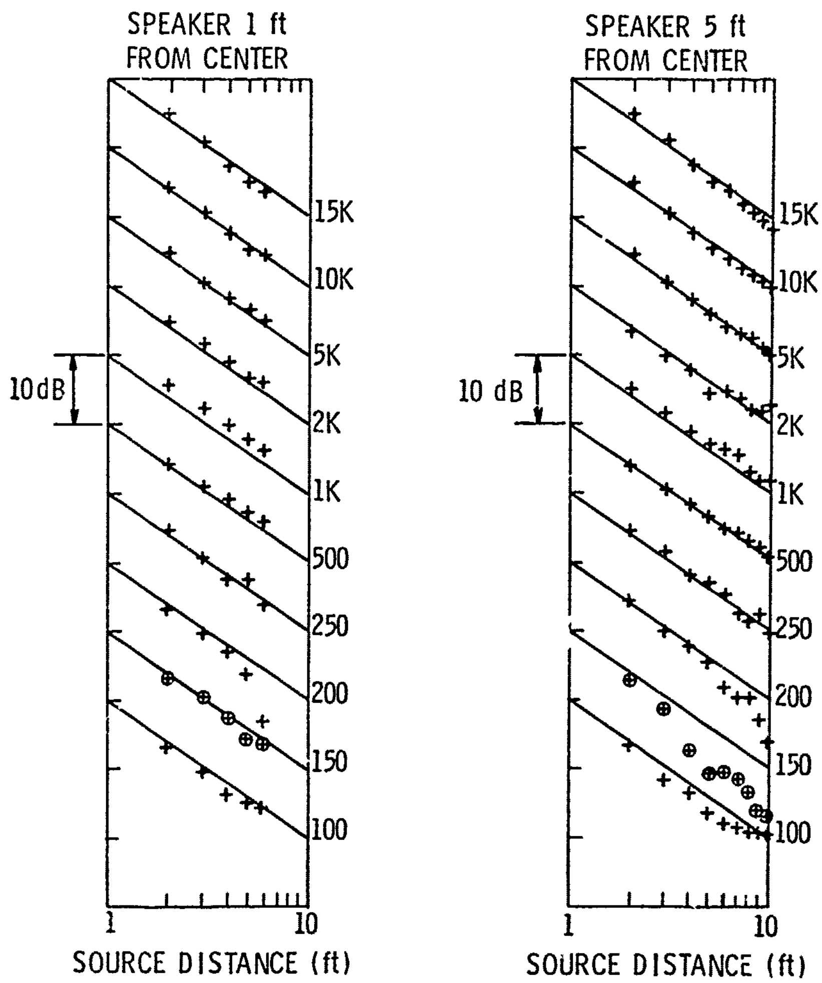

Figure 8 Inverse Square Law Measurement for Selected Tones

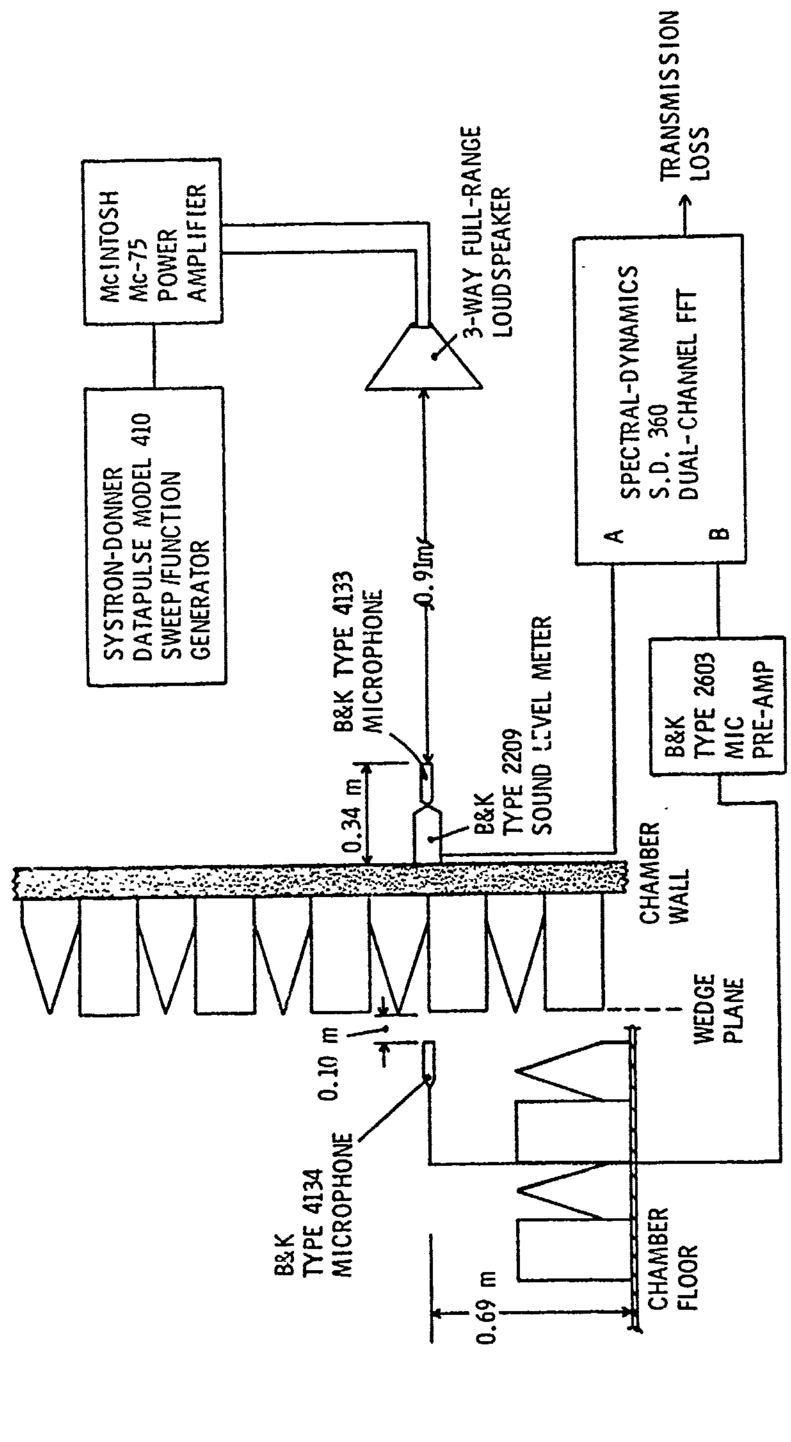

Figure 9 Instrumention Schematic For Transmission Loss Measurement

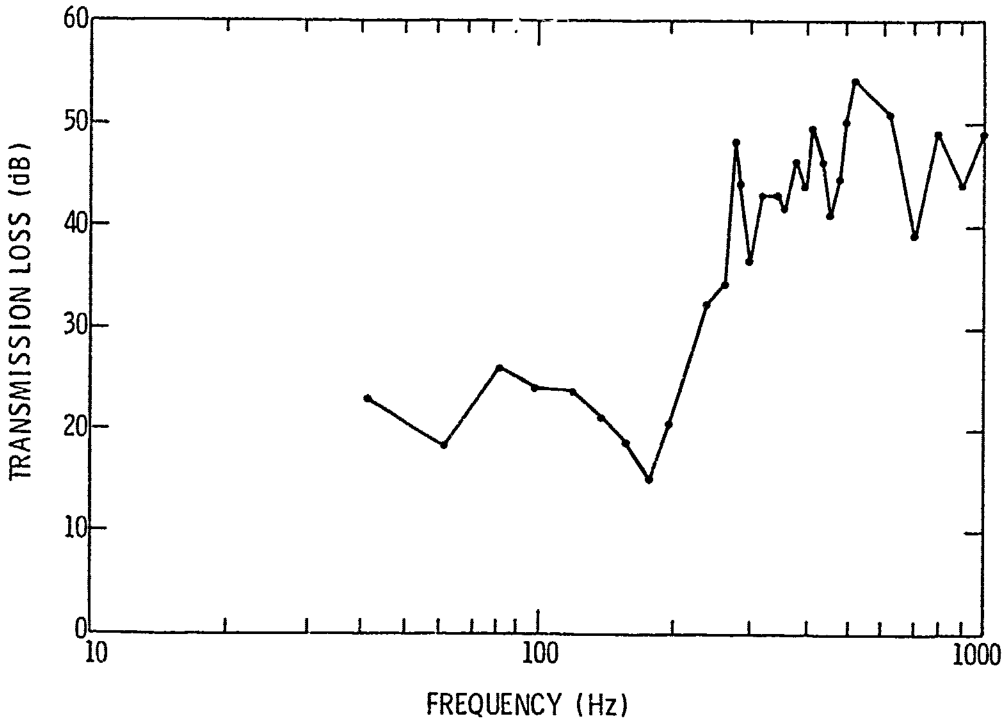

Figure 10 Transmission Loss for Side Wall (Away from Door)

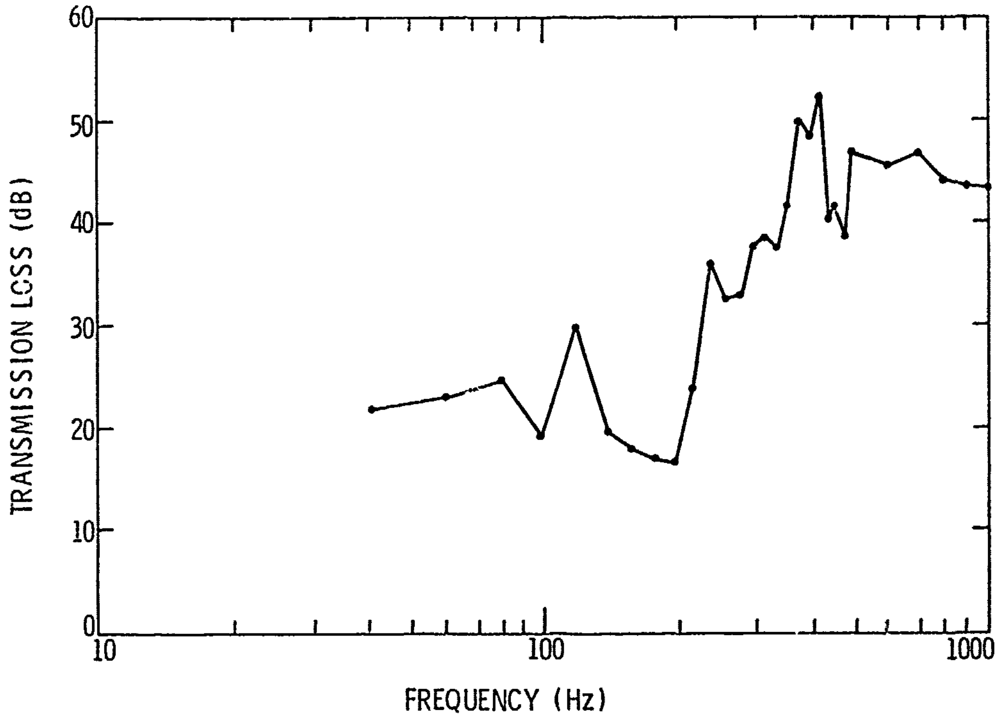

Figure 11 Transmission Loss Through the Door

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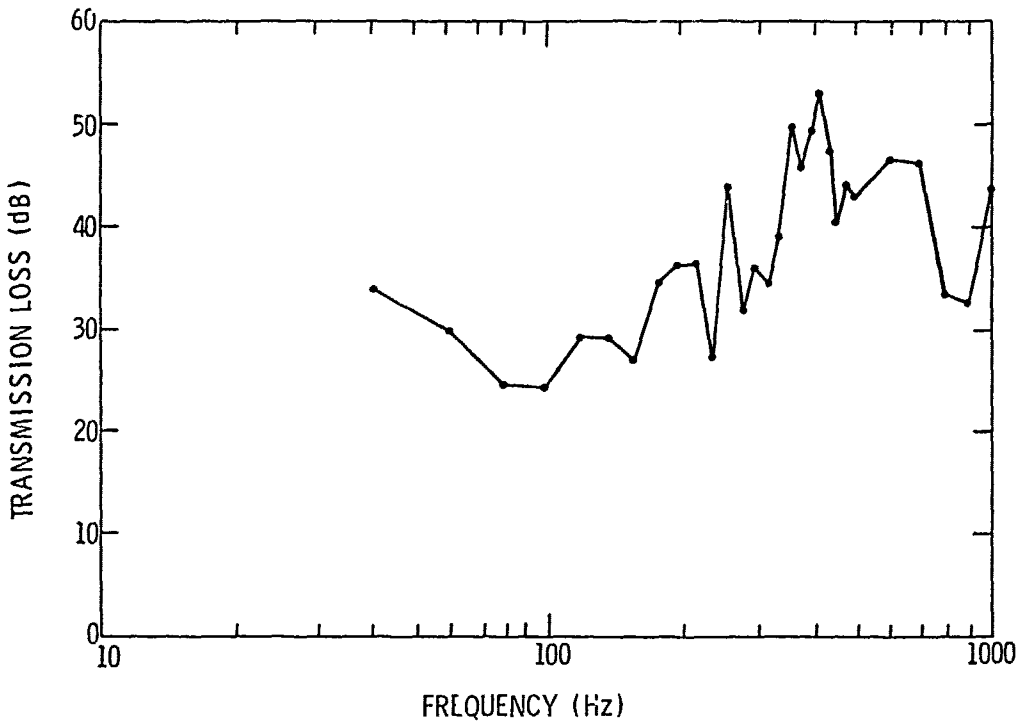

Figure 12 Transmission Loss for Fan Inlet Wall
(Fan duct closed)

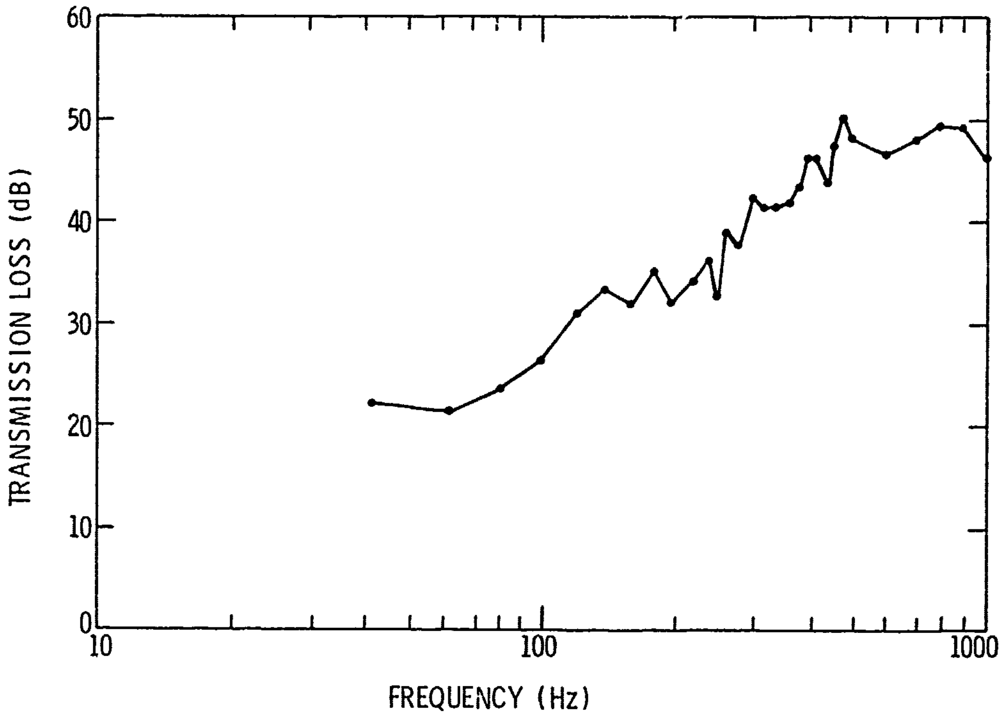

Figure 13   Transmission Loss for Air Intake Duct (3 ft. from end)

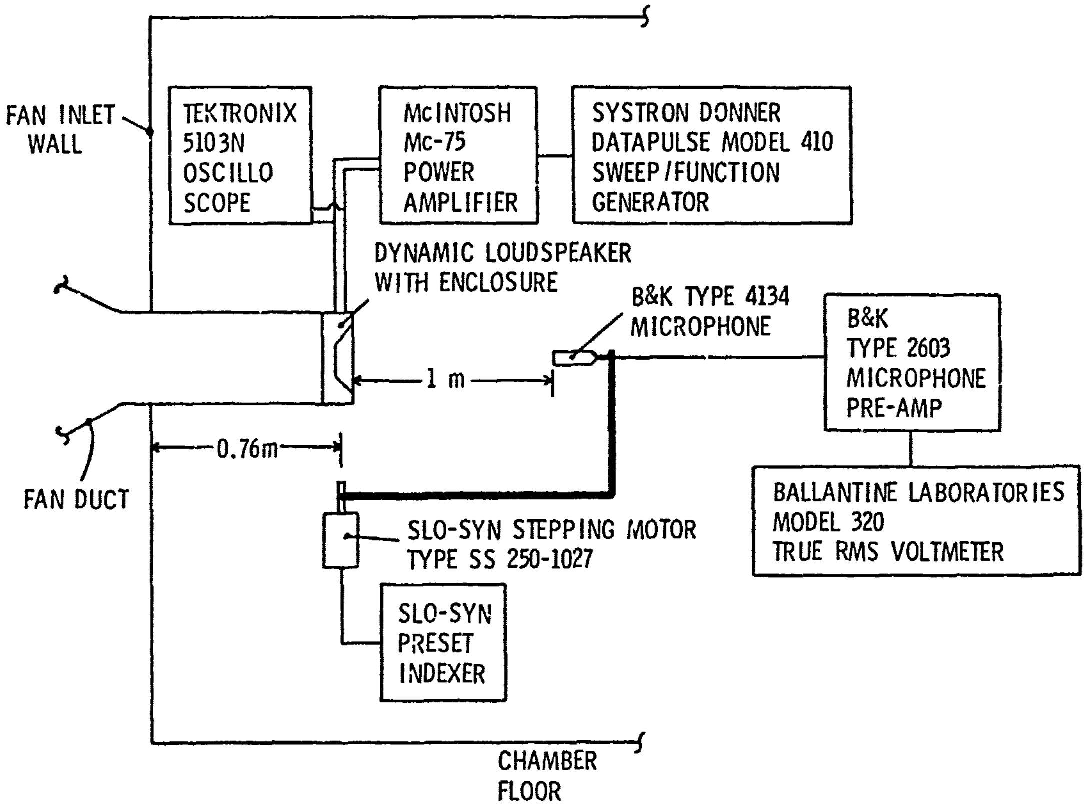

Figure 14 Instrumentation Schematic for Directivity Measurement (Side View)

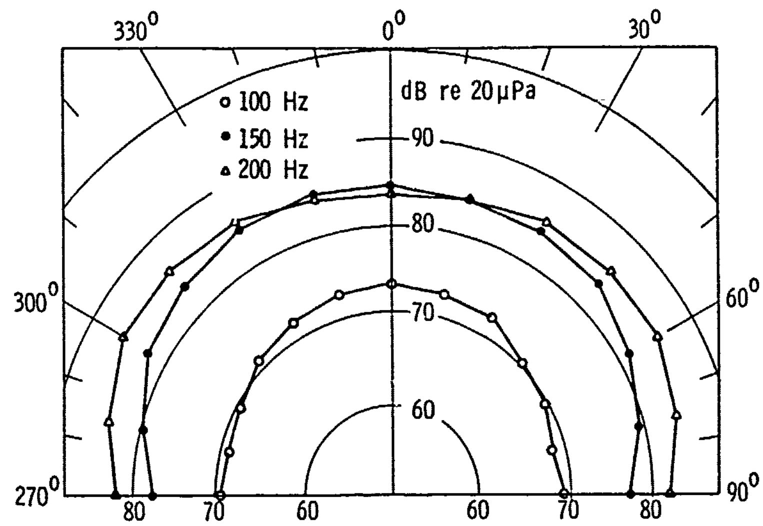

Figure 15 Tonal Directivity Patterns at 100 Hz, 150 Hz and 200 Hz (source positioned at fan inlet)

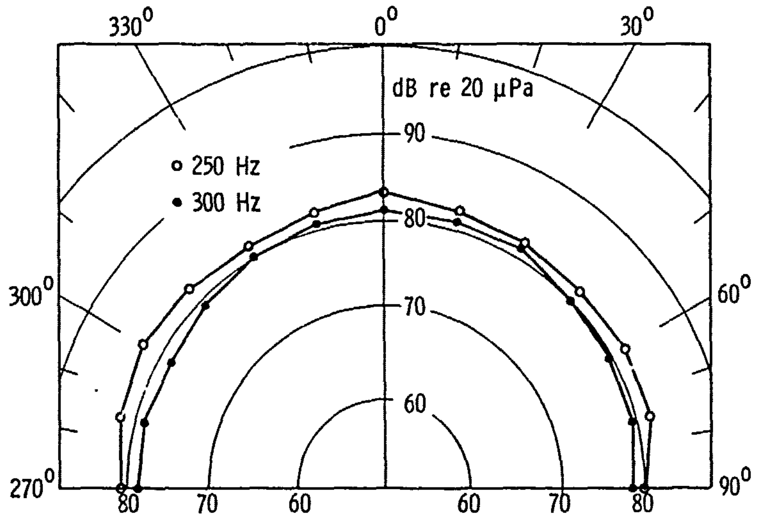

Figure 16 Tonal Directivity Patterns at 250 Hz and 300 Hz (source positioned at fan inlet)

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